# Laser status

## CTF3 Collaboration meeting

## CERN 23-25 November 2004

Marta Divall, Graeme Hirst, Emma Springate, Ian Ross, Guy Suberlucq, Roberto Losito

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# The outline of the talk

Reminder to the PILOT test results, Pilot to CTF3

•Milestones and deliverables

•Development programme

•Stability

•Steady-state operation

•Oscillator, preamplifier

•Thermal management

•Amplifier design (gain calculations)

•High power pumping diodes

•Amplifier head design

•Active feedback stabilisation

•Summary

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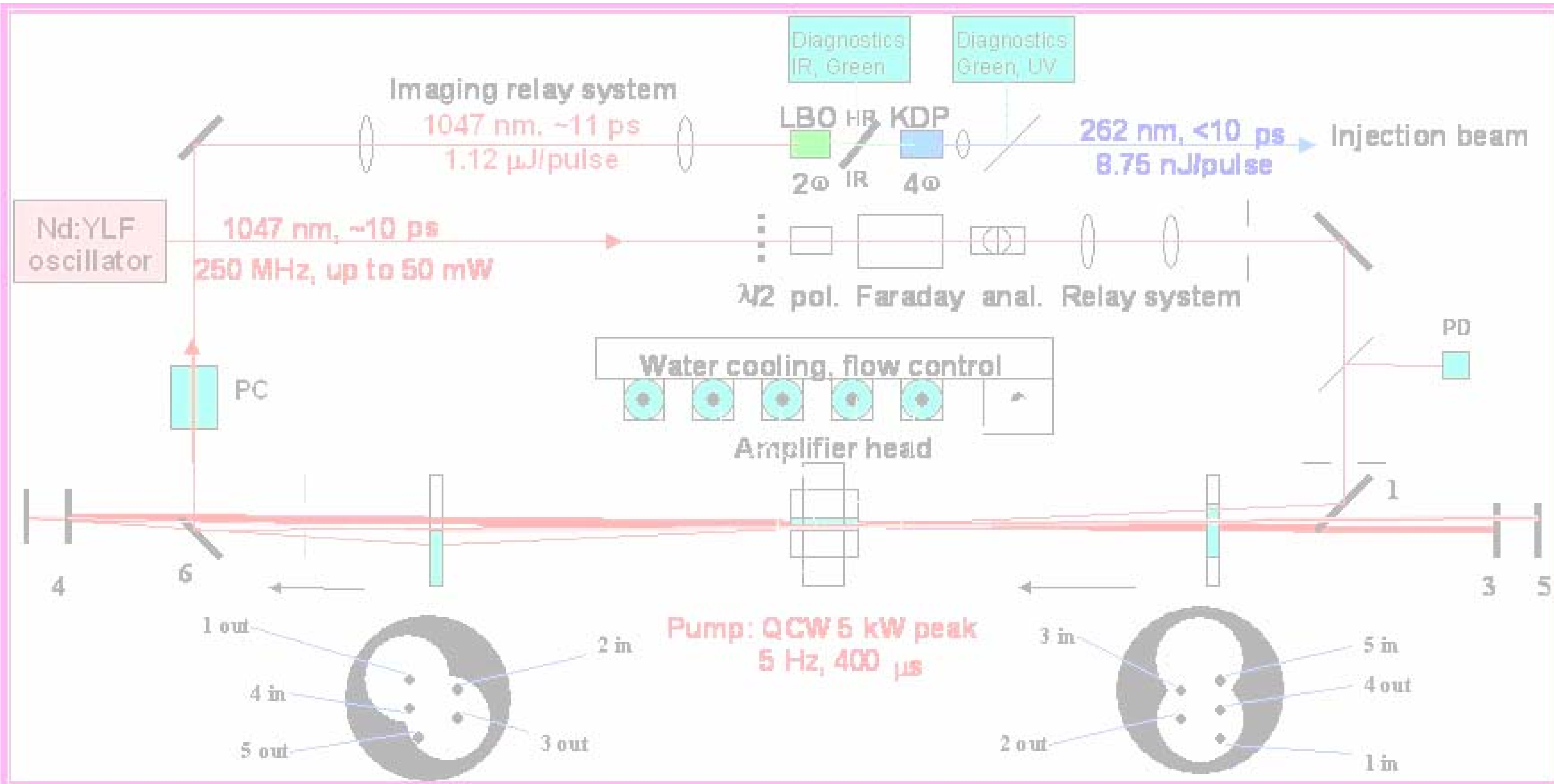
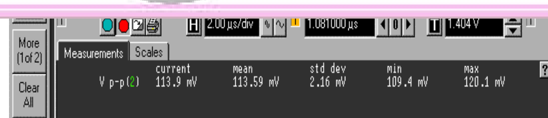
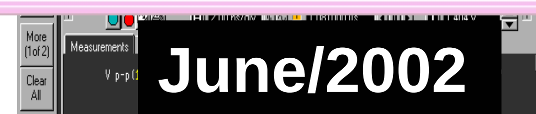
# PILOT TEST
# System layout

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# PILOT to CTF3
# Target parameters

| Target Parameters | Units | PILOT (achieved) | CTF3 |
|---|---|---|---|
| Charge / bunch | nC | **0.07** | **2.33** |
| Number of pulses | - | 250 | 2332 |
| Oscillator repetition frequency | GHz | **0.25** | **1.5** |
| Macro-pulse width | μs | 1 | 1.548 |
| $QE_{min}$ | % | 4 | 3 |
| Wavelength | nm | 262 | |
| $E_{cathode}$ / pulse | nJ | 8.75 | 370 |
| Optical path transm. | % | 52 | 70 |
| IR/UV conversion eff. | % | 1.5 | 7.4 |
| Stabilization transm. | % | | 70 |
| Repetition rate | Hz | 5 | **5 (1-50)** |
| $E_{OUT}$ / pulse (Amplifier) | μJ | **1.12** | **10** |
| Pulse train mean power | kW | **0.28** | **15** |
| Average power (UV) | mW | 1.4 | 116 |
| $E_{OUT}$ / pulse (oscillator) | nJ | **0.4** | **6.7** |

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# Milestones and deliverables

## Milestones

- Increase the power of existing oscillators (CCLRC-RAL, CNRS-LOA).
- Optimise the design of the amplifiers for required power output at minimum cost and complexity (CCLRC-RAL, CERN, CNRS-LOA).
- Efficiently convert the laser output wavelength to UV using new harmonic generator crystals (CCLRC-RAL, CERN, CNRS-LOA).
- Establish ultra-high stability including the use of charge and pointing stability feedbacks (CCLRC-RAL, CERN, INFN-LNF).

## Deliverables:

- High power oscillator.
- Specific amplifiers.
- Specific frequency conversion stages.
- Test of feedback systems.

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# Development programme



•Photo-cathode performance

•Oscillator
- high cw power ~30W
- 1.5GHz mode-locked

•Amplifier
- stable output pulse train
- high efficiency (1μm IR laser)
- good beam quality (lensing-effect)

•Feedback-control (<0.1%rms)
- laser diode pump current (μs)
- fast optical gate (Pockels-cell)
- accurate monitor (0.1%)

•Fourth harmonic generation
- high efficiency
- thermal management

•Optics
- good beam quality
- compensation for thermal lensing
- high damage thresholds

•Diagnostics
- stable operation
- high resolution for stability measurements
- 1-50Hz qcw signal detection

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# CTF3 amplifiers
# Stability

- Diode pumping
- Steady-state operation
- Feedback-system (Pockels cell, pumping current)
- Saturated amplifiers
- Saturated harmonic generation stages

- Temperature of the coolant (wavelength shift of diodes)
- Pump current stability
- Oscillator stability
- Ringing in the Pockels cell(s)
- Thermal effect in the harmonic generation stages

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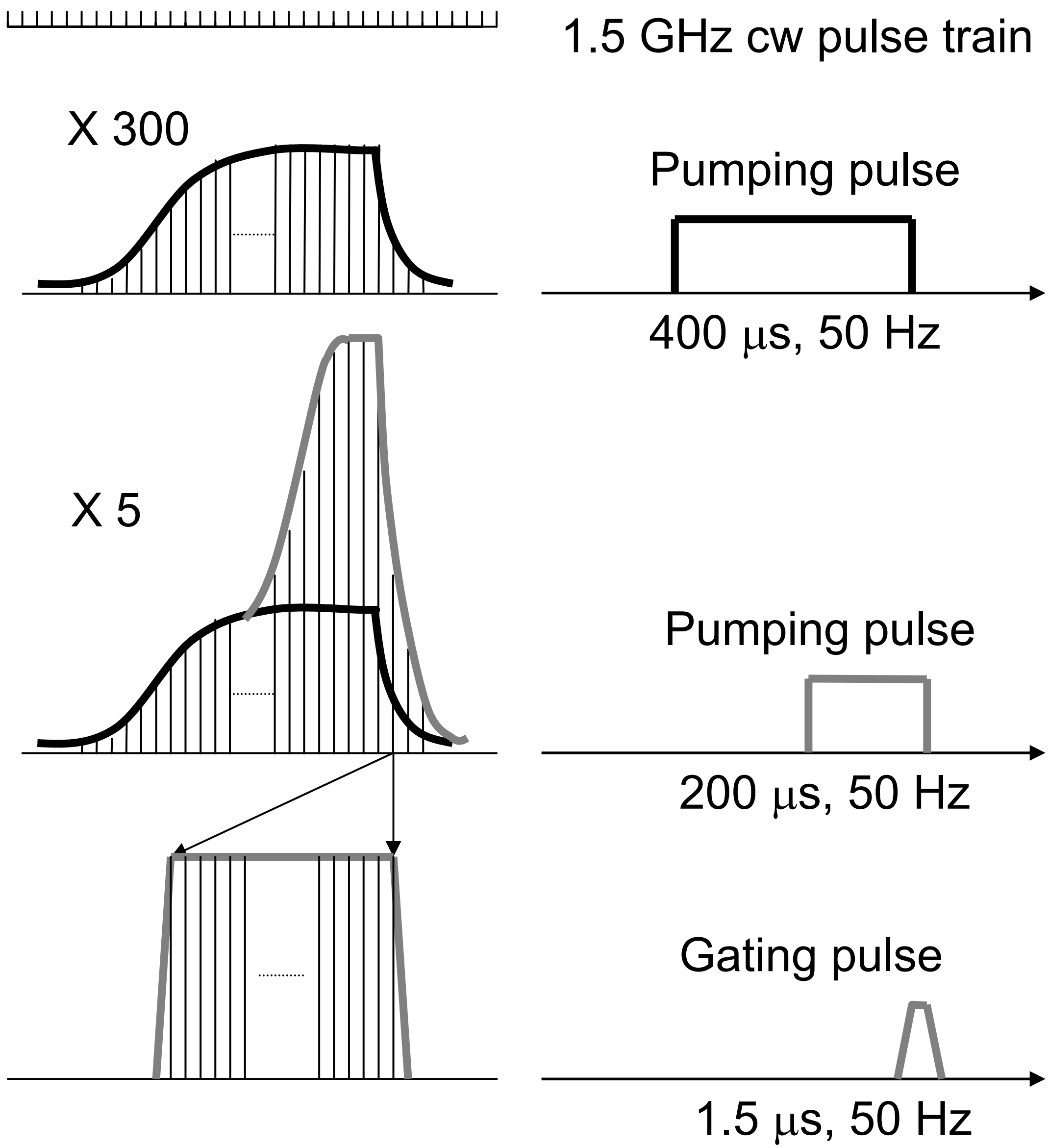
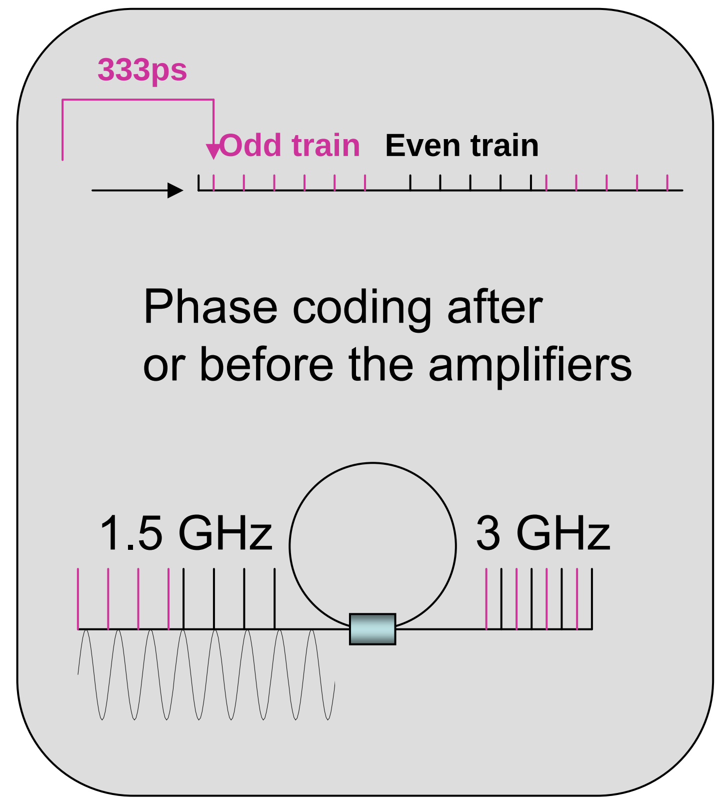
# Pulse structure

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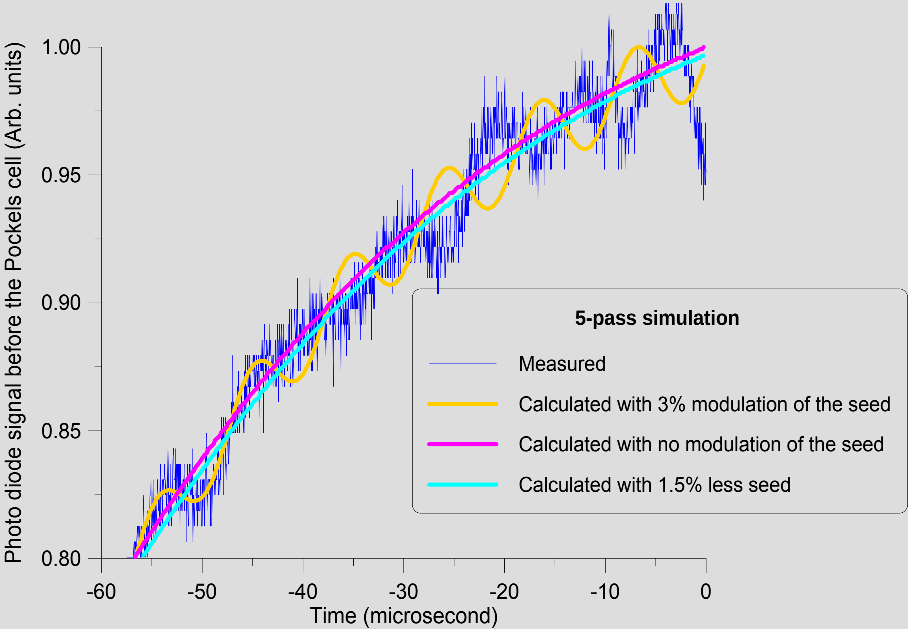
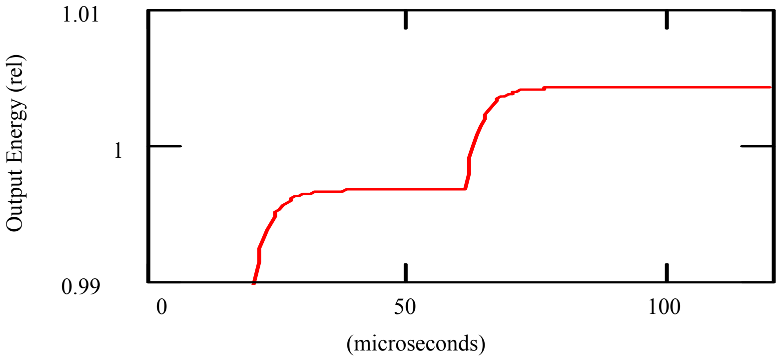
# CTF3 amplifiers

# Steady-state operation

$$P_{out} - P_{in} = \eta_p P_{abs} - \frac{\pi D^2}{4} F_{sat} \ln G \frac{(1+B)}{\tau_{fl}}$$

## Effect of seed modulation on the output




**Fast feedback stabilisation is needed!!**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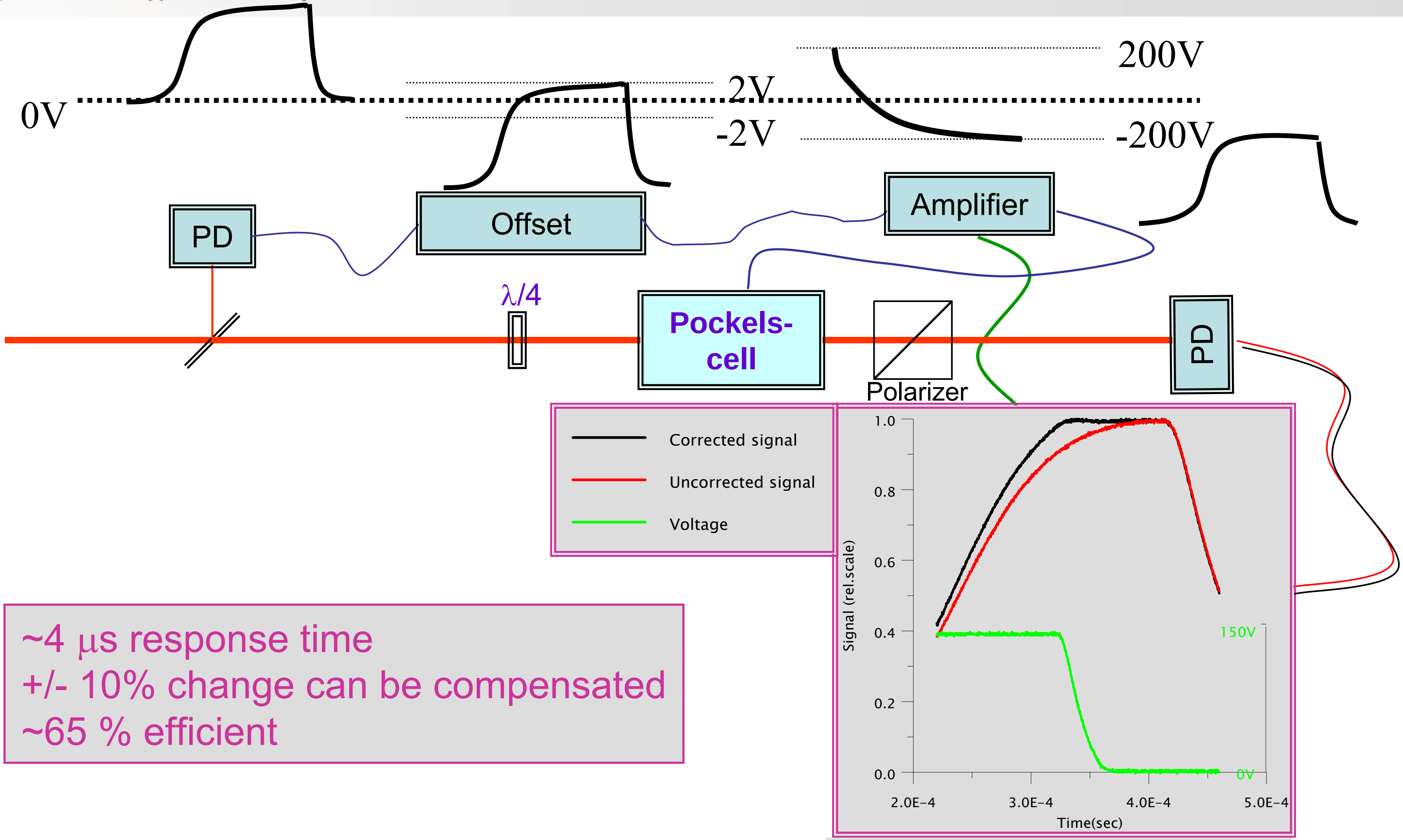
# Feedback stabilisation




~4 μs response time
+/- 10% change can be compensated
~65 % efficient

0.25%rms stability over 150μs

Speed needs to be improved (faster electronics)
Built in compensation for nonlinearity
Tests on the real system

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# Oscillator and preamplifier

| Parameter | unit | Specified in tender | HighQ |
|---|---|---|---|
| Laser gain medium | | Nd:YLF | |
| Wavelength | nm | 1047 | |
| Type of operation | | cw mode-locked | |
| Repetition rate | MHz | 1499.28 | |
| Average output power | W | > 0.2 | >0.2<br>3W, 10W with preamplifiers |
| Pulse width (FWHM) | ps | < 10 | |
| Timing jitter from an external 1.5 GHz RF source | ps | <±1 | <±1 (typ.) |
| Polarization | | Linearly polarized (1:500) | |
| Beam quality $M^2$ | | $TEM_{00}$ $M^2$< 1.2 | $M^2$< 1.2 |
| Beam pointing stability | µrad/°C | ±25 | ±25 |
| Beam size stability | | 5% rms size jitter | |
| Amplitude stability after a 1 h warm-up | | **< 0.2 % rms above the 100 kHz noise region<br><1% rms below the 100kHz noise region** | |
| Warranty | year | 1 | 1year/5000h of operation whichever is first |
| Repair and maintenance | | Available for at least 5 years | |

Tender has been sent out 28th of September 2004
Delivery will be February of 2005
The acceptance test will take place in CERN
The support will be valid in RAL after shipping
The company will provide an all optical timing jitter measurement

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# CTF3 amplifiers
# High average power, thermal management

- Thermal lensing
- Fracture limit of YLF for rod geometry 22 W/cm

**With 37 kW peak pumping power the thermal load ~21 W/cm assuming homogeneous pumping along the length of the rod.**

Fracture limit measurements for etched rods
Redesign the system with less power in the final amplifier

**Possible collaboration with Vienna University of Technology**

- **Development of etching technology for strengthening of LiYF4 laser crystals**
- **Development of ion exchange technology for strengthening of LiYF4 laser crystals**
- **Combination of etching and ion exchange techniques for strengthening of LiYF4 laser crystals**

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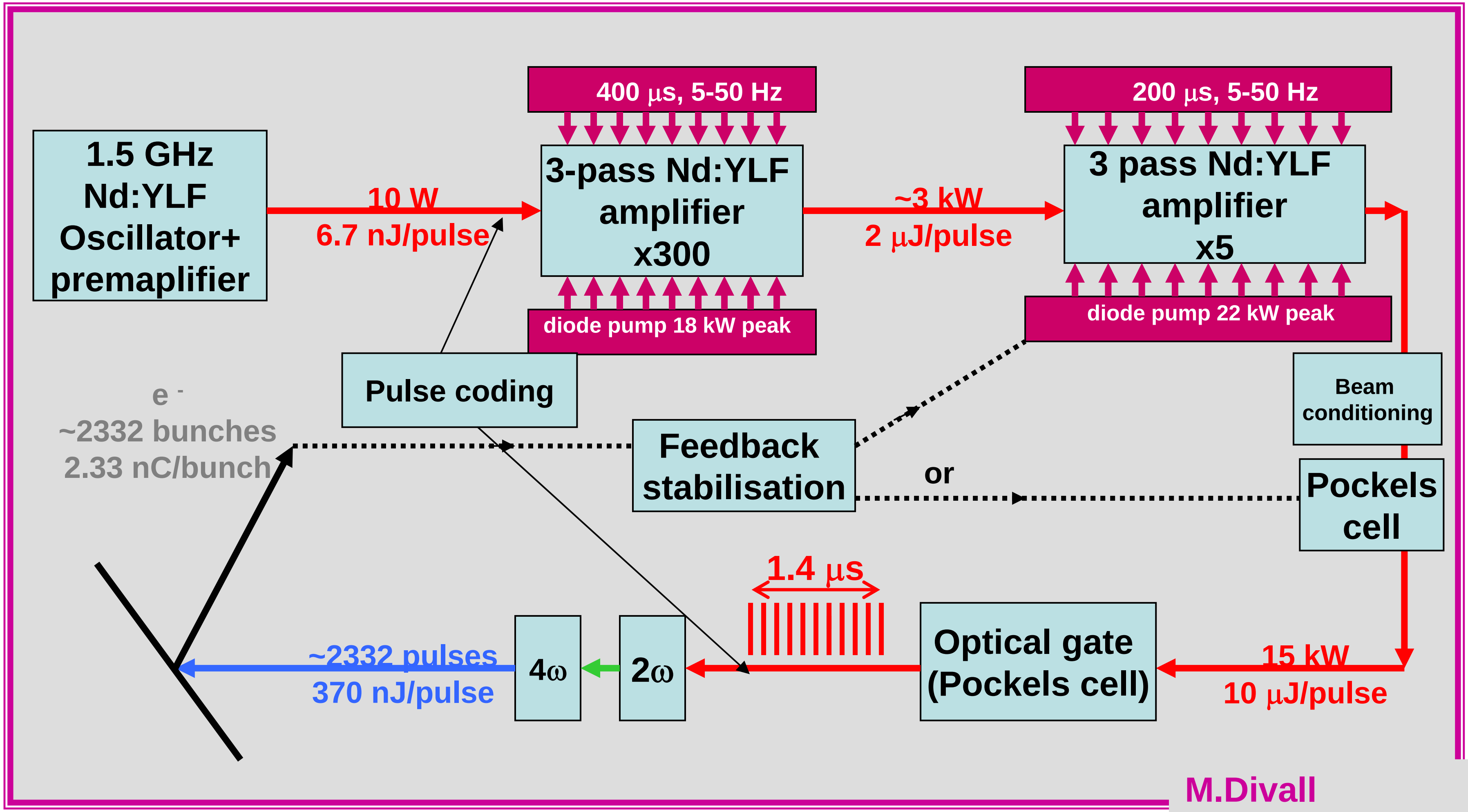
# CTF3

# New system layout

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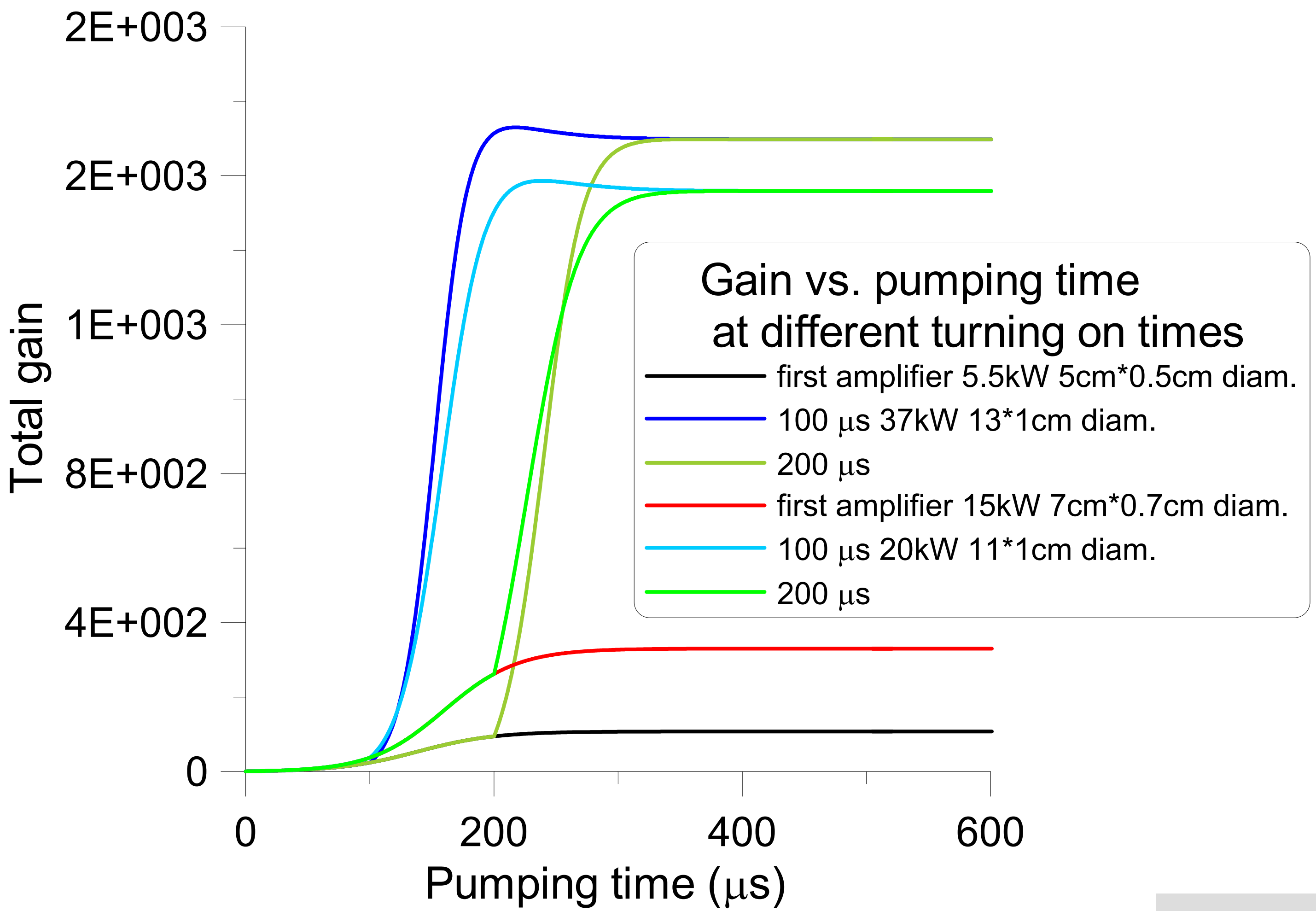
# Calculated gain curves

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# Consequences of the new design

## Advantages

- Less power in the second amplifier; safer thermal conditions
- 50 Hz operation is possible
- Higher overall efficiency
- Smaller gain and higher saturation in the second amplifier
- Similar power level in the amplifiers allows easier thermal lens compensation
(The two crystals can be rotated by $90^o$ to each other)

## Disadvantages

- Two completely new amplifier
- Higher cost

New specification for the diodes

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# Pumping diodes

## 1st amplifier

15 kW peak power 400 μs 50Hz pumping

**Asking for**

- 18 kW peak power for long lifetime $10^9$ shots
- 2.5% duty cycle for flexibility in pumping time
- Homogeneous pumping along the length of the 7 cm rod
- 5 fold geometrical configuration

## 2nd amplifier

20 kW peak power 200 μs 50Hz pumping

**Asking for**

- 22 kW peak power for long lifetime $10^9$ shots
- 2% duty cycle for flexibility in pumping time
- Homogeneous pumping along the length of the 11 cm rod
- 5 fold geometrical configuration

Specification needs to be put down for diodes
Homogeneous pumping has to be investigated
Surveying on the market has to be carried out

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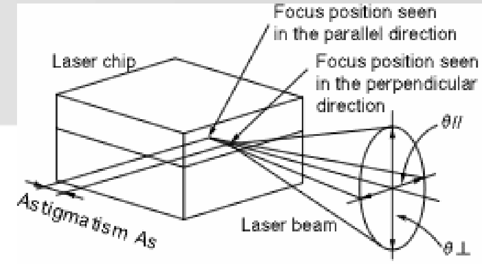
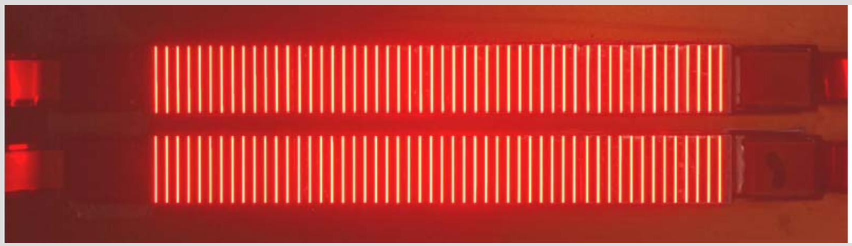
# The geometry

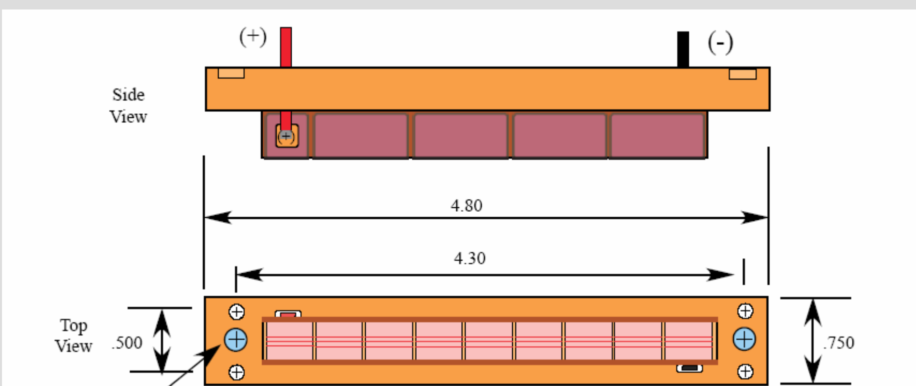



Astigmatism (As)



5kW
7.5 cm

Vertical stack
Need bigger spacing between arrays




5.5 kW
10.92 cm

Horizontal stack
Lensed option down to 1º

| Vertical stack | Horizontal stack |
|---|---|
| Mixed polarization ⊥ and ‖ to c-axis | Only perpendicular Polarization to c-axis |
| Some parallel to c-axis → higher absorption efficiency | More sensitive to Wavelength and so temperature |
| Too high power/length →several stacks needed or bigger spacing | More flexible in power/length |
| The divergence angle is ideal for 1 cm diameter rod | Special microlens arrangement needed for 6-8º divergence |
| Complicated to calculate pumping distribution | Easy to calculate pumping distribution |

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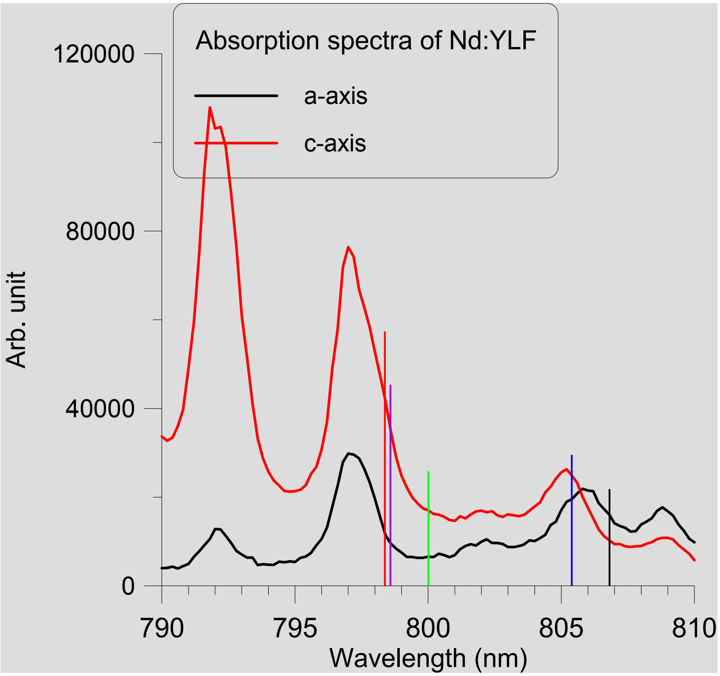
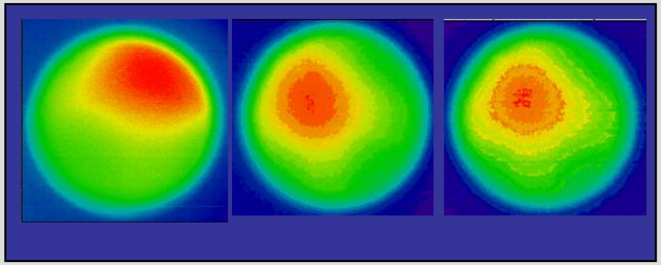
# Pumping distribution Measurements vs. calculations

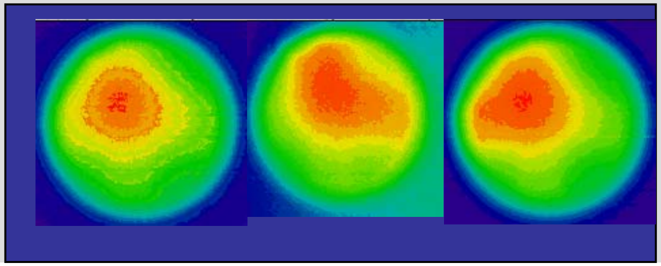


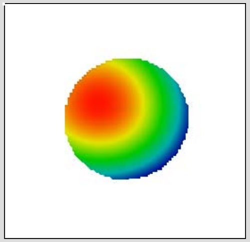

Changing the position of the diodes



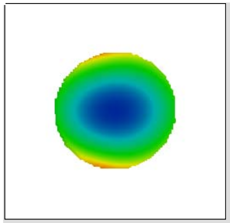
Measurements

Changing the temperature +/- 5°C

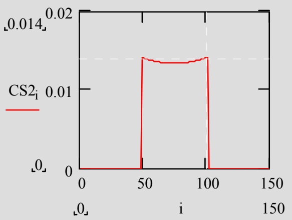




Fa2spec

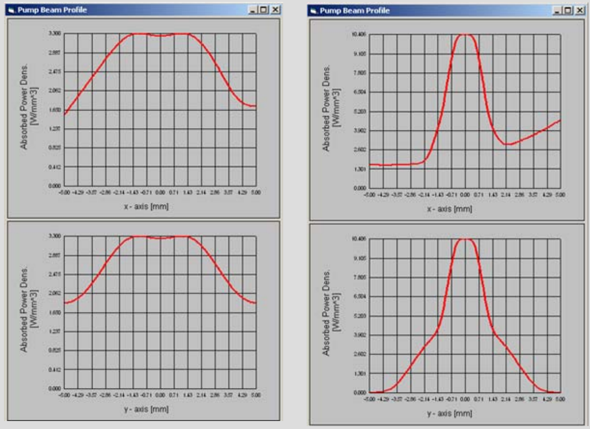


Fa2spec




792nm perpendicular to c-axis
(arrays along the optical axis)
0.5cm diameter rod

MathCad calculations




LasCad calculations

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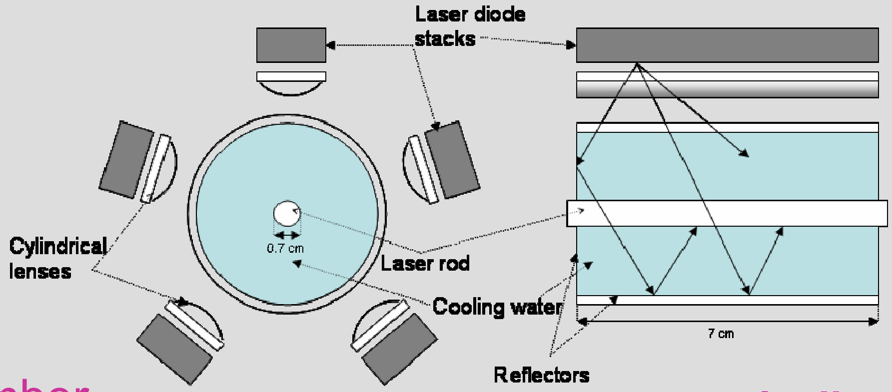
# Pumping diodes

- **Lensed option is too expensive, and no guarantee for good performance**
- **To buy more arrays to fill the length of the rod is cheaper, than a custom bar spacing**
- **The estimated cost for the two amplifiers together**

**max. 400.000 Euro**

The design calls for uniform pumping along the effective 7 cm of the rod, using either a single long stack or 2-3 shorter stacks.
External lenses will assure efficient coupling of the pump into the rod.




The tender was out by 1st of November

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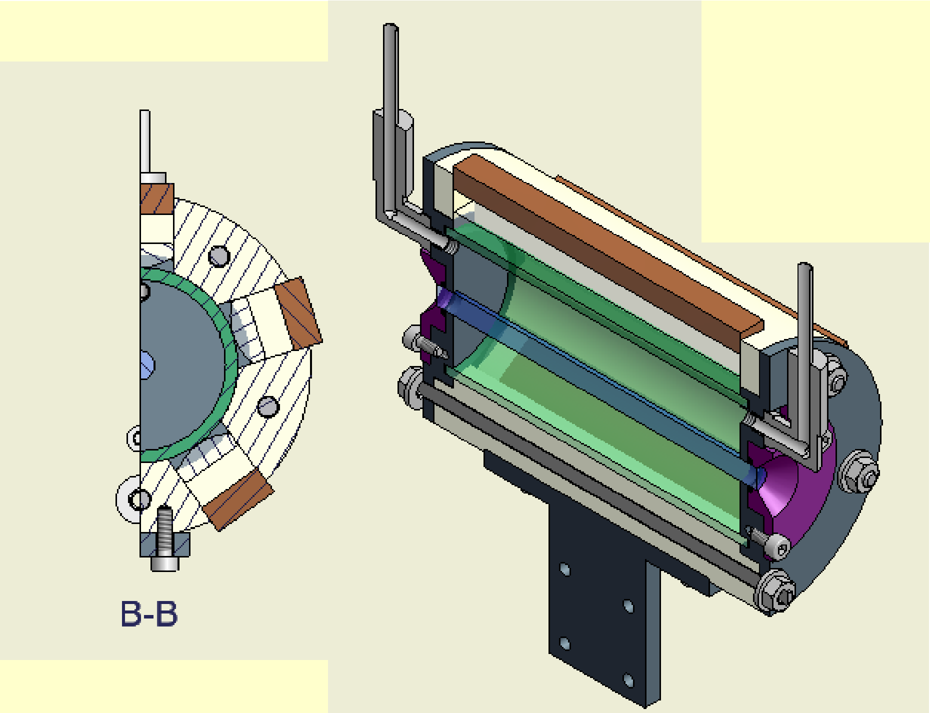
# The head design

- Simple water and electrical connections
- More accurate positioning of the focusing optics
- Easy assembly
- Possibility of rotating the rod in situ
- Alike design for the two amplifiers

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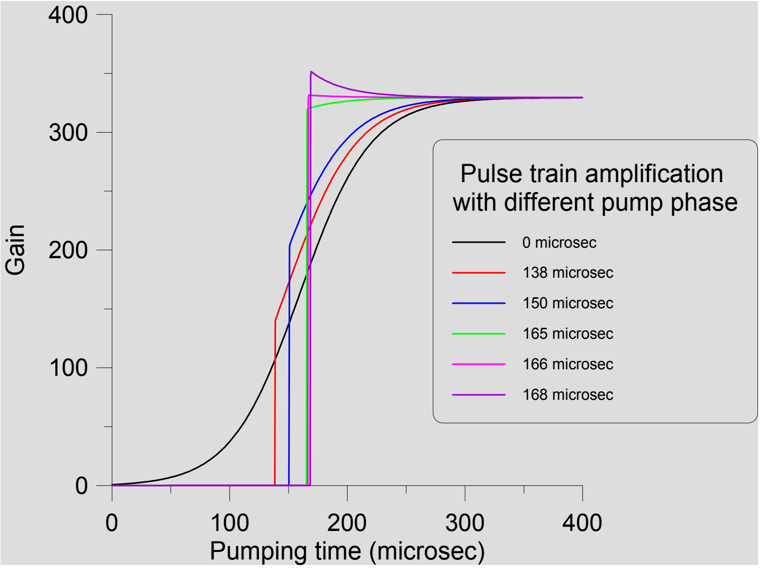
# Referees suggestions

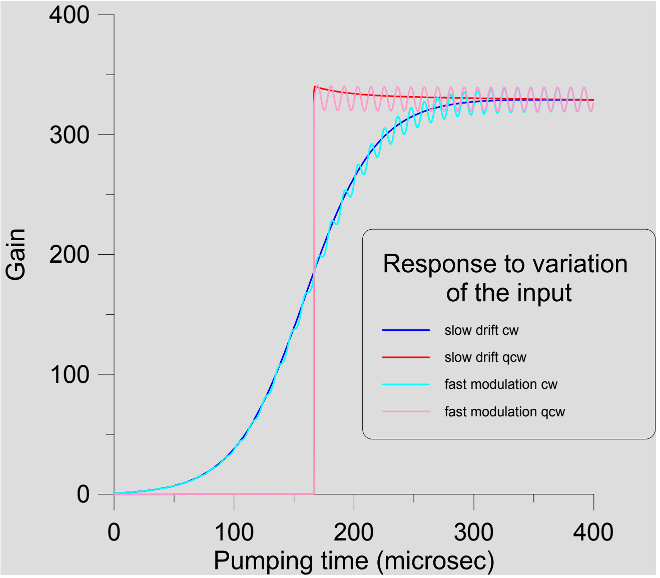
- Utilizing the energy stored in the laser rods during the total pump-up phase in more efficient way would probably allow to reduce the required amount of diodes and therefore the total costs of the laser system. It would also solve the problems with fracture limit of the laser rods. This option should be taken into account because it is of large interest for other institutions.

With burst mode less pumping time is needed. However to get the energy per pulse out from the system (peak power) the same pumping power needed. The required duty cycle for the diodes is standard, and the lifetime will depend on the number of shots, and not on the energy/pulses. So cost-wise the qcw solution for the seed does not make a difference. However it would help with thermal management, but in the new design this problem is solved, and with thermal power/unit length being the same in both amplifiers the thermal lensing can be easily compensated.
With steady-state operation in the case is slow input variations the output will remain the same, while in the case of burst mode operation this can cause very high overshoot (gain) at the front of the train. For safe operation the system requires sophisticated feedback stabilization and timing control.

- It may worthwhile to consider an oscillator running in burst-mode instead of CW mode.

This type is laser is not common on the market. Stable operation is guaranteed in a cw mode-locked laser.





*IEEE JOURNAL OF QUANTUM ELECTRONICS, VOL. 34, NO. 10, OCTOBER 1998*
*Feedback-Stabilized Nd:YLF Amplifier System for Generation of Picosecond Pulse Trains of an Exactly Rectangular Envelope*
***Ingo Will, Armin Liero, Dieter Mertins, and Wolfgang Sandner***



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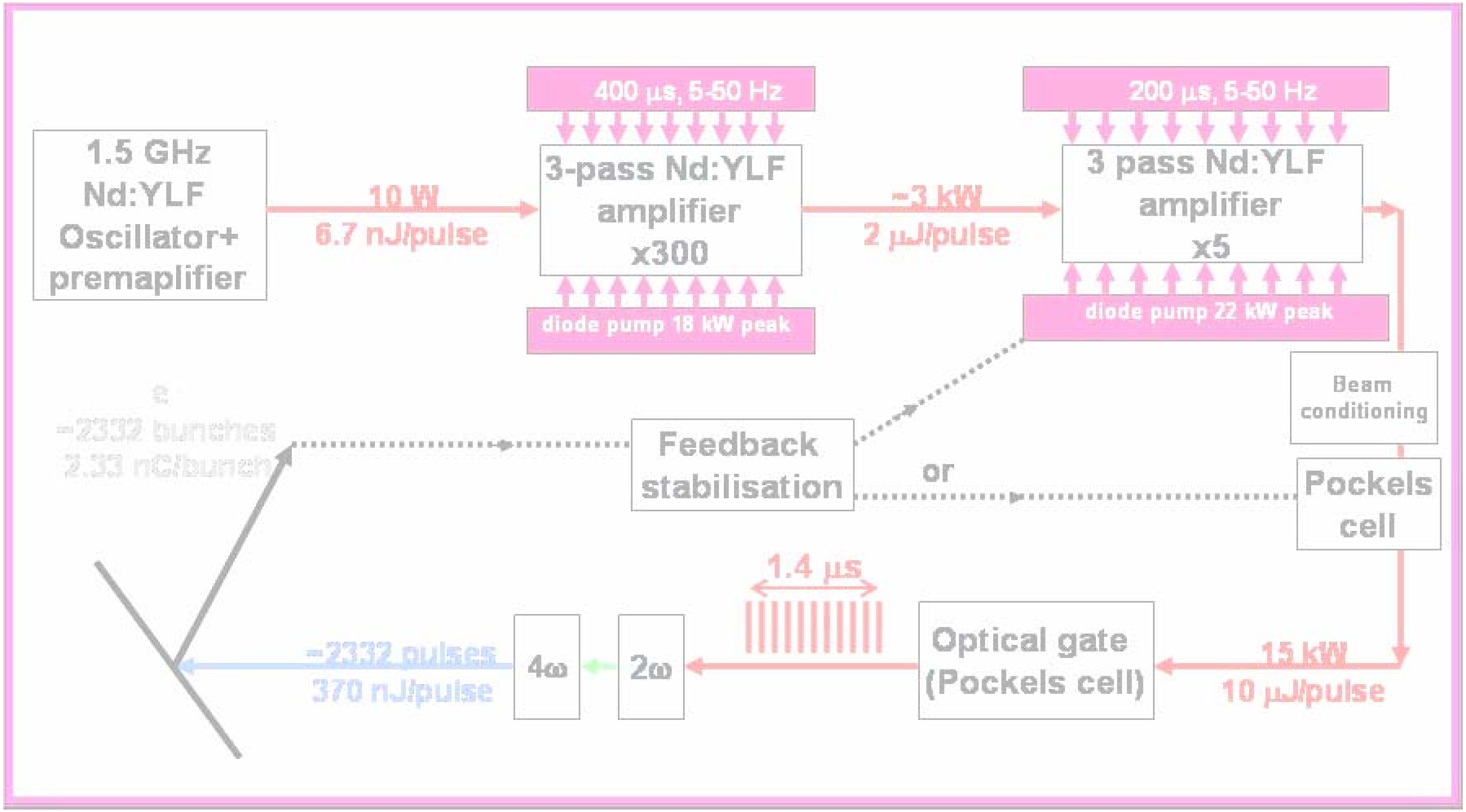
# Summary

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